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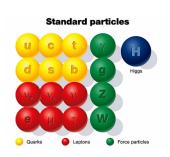
Ultracold Neutrons at LANSCE

Leah Broussard

Los Alamos National Laboratory

February 29, 2014

The Standard Model (and Beyond)



Some Curiosities

- · Lots of "Why?'s"
 - Why 3 generations?
 - Why so many parameters?
 - Why these masses?
 - Why left-handed weak interaction?
- What is Dark Matter?
- Why so much matter?
- Where is gravity?
- And more...

Finding the missing pieces

- High Energy frontier (LHC) vs. Precision frontier (beta decay)
- Complementary approaches
 - High energy: Direct search for heavy particles
 - Precision: Measure deviations from SM expectation

Neutron Beta Decay



- Semileptonic charged weak interaction
- Standard Model: V A (left-handed)
- Lifetime \sim 15 minutes

What we can measure:

Total decay rate (lifetime):

$$\frac{1}{\tau_n} = W = K \left(G_F \mathbf{V}_{ud} \right)^2 \left(1 + 3 \left(\frac{G_A}{G_V} \right)^2 \right) (1 + \Delta_R) f_n p_e E_e (E_0 - E_e)^2 \left[1 + m_e \mathbf{b} \frac{f_b}{f_n} \right]$$

• Angular correlations: $\frac{dW}{dE_{\rm e}d\Omega_{\rm e}d\Omega_{\nu}} \propto$

$$\begin{array}{l} \frac{dW}{dE_e d\Omega_e d\Omega_{\nu}} \propto \\ p_e E_e (E_0 - E_e)^2 \left[1 + \mathbf{a} \frac{\vec{p_e} \cdot \vec{p_{\nu}}}{E_e E_{\nu}} + \mathbf{b} \frac{m_e}{E_e} + \langle \vec{\sigma_n} \rangle \cdot \left(\mathbf{A} \frac{\vec{p_e}}{E_e} + \mathbf{B} \frac{\vec{p_{\nu}}}{E_{\nu}} + \mathbf{D} \frac{\vec{p_e} \times \vec{p_{\nu}}}{E_e E_{\nu}} \right) \right] \end{array}$$

Testing the Standard Model

- A, $a + \tau \rightarrow V$, A interactions (V_{ud} , RL symmetry, ...)
- B, b \rightarrow S, T interactions (BSM interactions, MSSM, ...)

Ultracold Neutrons

Class	Energy	Source		
Fast	> 1 MeV	Fission reactions / Spallation		
Slow	eV – keV	Moderation		
Thermal	0.025 ev	Thermal equilibrium		
Cold	μ eV – meV	Cold moderation		
Ultracold	≤ 300 neV	Downscattering		

How cold is Ultracold?

- Temperature < 4 mK
- Velocity < 8 m/s
- Usain Bolt \sim 12 m/s



UCN can be bottled

- Gravitational (V = mgh): 100 neV / meter
- Magnetic ($V=-\vec{\mu}\cdot\vec{B}$): 60 neV / Tesla

• Material
$$\left(V = \frac{2\pi\hbar^2 Nb}{m}\right) \left\{ egin{array}{ll} 58\,{\rm Ni} : & 335\,{\rm \,neV} \\ {\rm DLC} : & 250\,{\rm \,neV} \\ {\rm BeO} : & 250\,{\rm \,neV} \\ {\rm Cu} : & 170\,{\rm \,neV} \end{array} \right.$$

Manipulating UCN

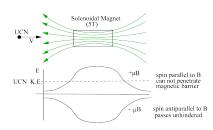
Material bottles: UCN guides

- Features of good UCN guides:
 - Low "loss per bounce" $(< 10^{-5})$
 - High Material Potential (> 200 neV)
 - Low depolarization ($\sim 10^{-6}$)



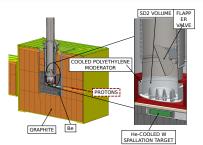
Magnetic selection: UCN polarizers

- Neutron magnetic moment μ due to spin
- 100% polarization possible



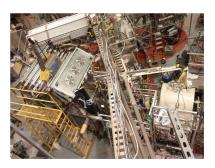
(note: neutron magnetic moment is negative)

Ultracold Neutron Facility at LANSCE

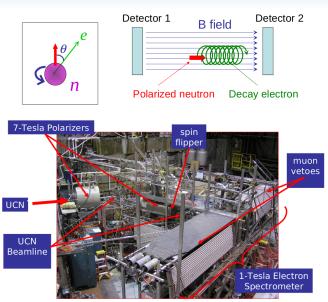


Decay Trap UCN Monitor Spectrometer AFP UCN Monitor 7 T Polarizer / Spin-Flipper Switcher Gate PPM Valve Shielding Switcher UCN Guide UCN Monitor UCN SD2 Gate Valve Source UCN Monitor

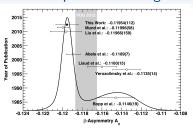
- 800 MeV proton beam + tungsten target → spallation neutrons
- Single scatter in solid deuterium: CN→UCN + phonon
- Remove phonons: SD2 cooled to 4K
- "Flapper" shields UCN from SD₂
- 50 UCN/cc at shield wall
- Pulsed beam: Low background

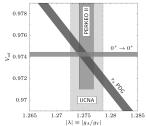


Experimental Programs at the UCN Facility: UCNA



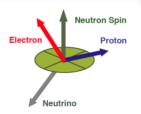
Experimental Programs at the UCN Facility: UCNA



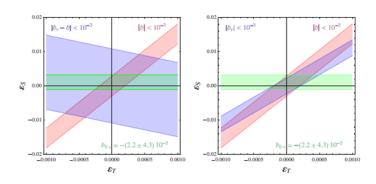


Corr. +/- Uncertainty (%)	Mendenhall (2013)	In analysis (TBS 8/14)	Next Step	Source of improvement
Statistics	+/- 0.46	+/- 0.40	+/- 0.28	Decay rate!
Depolarization	+0.67 +/- 0.56	+0.67 +/- 0.1	+0.6 +/- 0.1	Shutter+ ex situ
Backscatter	+1.36 +/- 0.34	+0.5 +/- 0.15	+0.5 +/- 0.15	Thin windows
Angle effect	-1.21 +/- 0.30	-0.8 +/- 0.2	-0.8 +/- 0.1	Windows+APD
Energy Reconstruction	+/- 0.31	+/- 0.08	+/- 0.08	Xenon + LED
Total Sys.	+/- 0.82	+/- 0.28	+/- 0.22	
Total	+/- 0.94	+/- 0.5	+/- 0.35	
	Dominated by systematics	Dominated by statistics	Intended to be balanced	

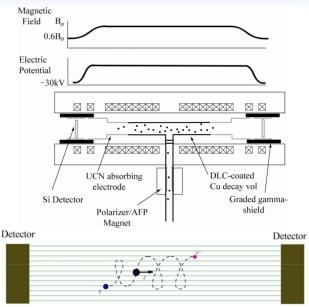
Experimental Programs at the UCN Facility: UCNB



- 3-body decay: ν -asymmetry from proton/electron directions
- **B** is sensitive to **b**, $\mathbf{b}_{\nu} \rightarrow$ non-Standard Model Scalar and Tensor interactions



Experimental Programs at the UCN Facility: UCNB



Experimental Programs at the UCN Facility: UCNB

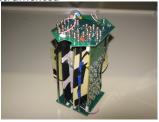
Novel thick, large area, highly segmented silicon detectors

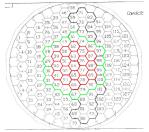


Biased to -30 kV to accelerate protons



Custom preamplifiers: 24 ch instrumented





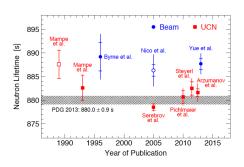
Experimental Programs at the UCN Facility: UCN_T

Neutron lifetime

- Precise tests of Standard Model
- Big bang nucleosynthesis
- Reactor and solar neutrino flux predictions

Beam vs. Bottle

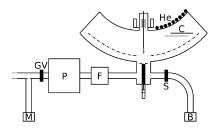
- Beam experiments: neutron flux?
- UCN bottle experiments: loss in the walls?

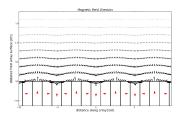


Experimental Programs at the UCN Facility: UCN_T

Magneto-gravitational Trap

- World's largest permanent magnet array
- Neutrons bounded by magnetic field on bottom, gravity on top
- No wall losses!

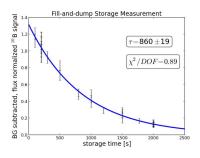






Experimental Programs at the UCN Facility: UCN_T

First storage time measurement (Feb 2013)



Current status

- Precision studies of systematics
- In-situ UCN counting
- Quasibound UCN cleaning?
- Monte Carlo UCN simulations
- Goal for prototype: 1 s precision measuremnt
- Ultimate experimental goal:
 0.1 s precision